DMU

Advanced Journal of Interdisciplinary Studies 9(2025) 1678-1690

AJIDS

Journal homepage: www.ajids.dmu.edu.et

Volume 9(1), June 2025

Comparative Decomposition and Nutrient Release of Leaf Litter from Three Indigenous Tree Species in E/Gojjam, North Central Ethiopia

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Abstract

A field- and laboratory-based study investigated the nutrient composition and decomposition rates of leaf litter from three indigenous tree species: *Cordia africana*, *Croton macrostachyus*, and *Hagenia abyssinica*. Fifteen leaf samples from each species grown under similar soil, topographic, and age conditions were collected. For the decomposition study, 36 litterbags, each containing 10 g of oven-dried leaf litter, were placed on the soil surface in randomized plots. Leaf litter samples were analysed for total nitrogen, phosphorus, potassium, carbon, lignin, and polyphenols using standard protocols, including micro-Kjeldahl digestion, wet acid digestion, flame photometry, dry combustion, and spectrophotometer.. Results indicated that *C. macrostachyus* had higher potassium content than *C. africana* and *H. abyssinica*. Both *C. macrostachyus* and *H. abyssinica* exhibited higher nitrogen and phosphorus but lower carbon levels compared to *C. africana*. Conversely, *C. africana* showed higher concentrations of C:N ratio, lignin, lignin/N, polyphenol, polyphenol/N, and (lignin + polyphenol)/N. Decomposition patterns varied significantly among species: *H. abyssinica* litter decomposed within 2–3 months, *C. macrostachyus* within 3–4 months, while *C. africana* required 7–8 months. Mass loss and nutrient release were substantially greater in *H. abyssinica* and *C. macrostachyus* than in *C. africana*. The findings suggest that integrating all three species into agroforestry systems can enhance soil fertility and crop productivity, as *C. africana* provides extended soil cover while *H. abyssinica* and *C. macrostachyus* rapidly release nutrients.

Keywords: Agroforestry, *Cordia africana*, *Croton macrostachyus*, Decomposition, *Hagenia abyssinica*, Leaf litter, Nutrient release.

1. Introduction

Nutrient and energy transfer from plants to the soil is largely initiated by litterfall, making it a fundamental component of nutrient cycling. In agroforestry systems, the effectiveness of nutrient cycling is closely tied to the decomposition rate of tree leaf litter, which returns organic matter and nutrients to the soil (Sarvade et al., 2014).As a key element of the biogeochemical cycle, litter fall contributes organic material, energy, and essential nutrients from vegetation to the soil environment (Zhu et al., 2021).

Soil formation and nutrient cycling are influenced by litter fall decomposition, which generates organic matter (Hobbie, 2015). Decomposition is mainly governed by environmental factors, the chemical composition of leaf litter, and the presence of decomposing organisms (Bani et al., 2018). Research has shown notable differences in leaf litter decomposition rates among species. The role of litter decomposition in regulating ecosystem carbon storage and nutrient cycling is vital, as it affects both the nutrient status and productivity of vegetation (Giweta, 2020). Nutrient dynamics related to decomposition rates are critical for determining the nutrient status of an ecosystem (Robertson & Paul, 2000).

Rapid loss of hydrosoluble chemicals, increased microbial activity, and nutrient leaching and release are features of the first stage of decomposition (Hossain et al., 2014). Although components such as lignin and polyphenols become more important in later phases, studies indicate that nitrogen (N) can predict breakdown rates in the beginning (He et al., 2019). Additionally, it has been discovered that the initial ratios of lignin, polyphenol, lignin:N, lignin + polyphenol:N, and C:N influence the rates of mineralization and breakdown (Vahdat et al., 2011).

Hagenia abyssinica, *Croton machrostchyus*, and *Cordia africana* are the three indigenous tree species that were the subject of this study because they improve the physical and chemical characteristics of the soil, which greatly increases crop output. These plants are well known among Ethiopian farmers and provide a number of advantages, including fuel wood, shade, fodder, lumber, and soil conservation (Bekele & Abebe, 2018). Despite their significance in crop productivity and soil fertility, these species have not received much attention. Since leaf litter is a significant contributor to nutrient return through aboveground litterfall, this research project intended to investigate the chemical makeup of leaf litter and its breakdown to release nutrients into the soil (González-Rodríguez et al., 2011)

2. Materials and Methods

2.1.Study area

The study was carried out at the Wonka Peasant Association in the Gozamin District, East Gojjam Zone, Ethiopia, which is located between latitudes 10 °20' N and longitudes 37 °43' E (Figure 1). The average yearly temperature is 18 °C, and the elevation is 2200 m above sea level. This region has both plateaus and valleys. The region receives 1628 mm of rain each year. Litosol, Acrisol, Regosol, Nitisol, Vertisoil, and Luvisol are the categories under which the soils are categorised. The Gozamin District Agricultural Report (2023) states that the most prevalent tree and shrub species are *Hagenia abyssinica*, *Croton macrostachyus*, *Cordia africana*, *Milletia ferrugina*, *Accacia decurrens*, *Accacia saligna*, *Gravellia robusta*, *Sesbania sesban*, and Leucina leucocephala.

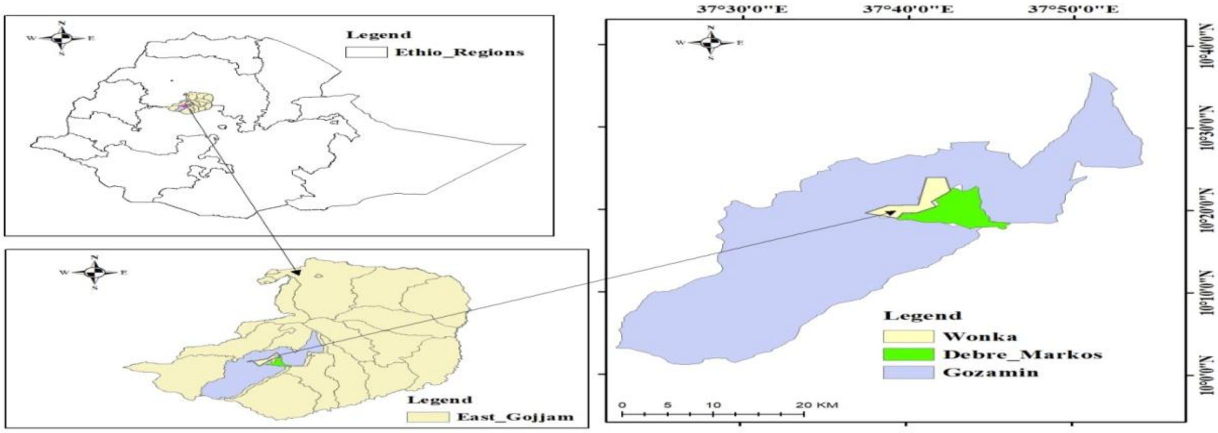

Figure 1. Map of the study site

2.2.Leaf collection and decomposition

Due to the fact that May 2023 was a peak leaf litter fall month in the study location, nine sampling trees (3 tree species × 3 replications) established in similar soil and topography with similar ages were chosen at random by drawing lots to have their abscised leaves collected. Abscised leaves were yellow in all three species, making them easy to identify from green leaves. According to (Kumar & Kunhamu, 2022)., the branches of particular trees were chopped off, and the leaves that had been abscised were collected from the ground. For each unique sampling tree, at least fifteen leaves were taken from every canopy location and handled independently. After air drying, the samples were oven-dried for 24 hours at 65 ^{o}C. According to Mahari (2014), a portion of each sample was broken into powder and run through a 0.5 mm mesh screen for further chemical analysis to be conducted in the lab. Another portion was used immediately for a decomposition research close to Wonka Tree Nursery.

Leaf litter decomposition was conducted using the standard litterbag technique, as described by (Devendar et al., 2022). Oven-dried leaf litter (10 g per batch) was placed in individual 20 × 20 cm plastic mesh bags with a 2 mm mesh size. These litterbags were then returned to the study site and randomly distributed on the soil surface across three separate plots using a randomised block design. To simulate natural conditions, the bags were positioned just beneath the existing litter layer, allowing exposure to soil-dwelling decomposers and ambient weather conditions. Each bag was secured to the forest floor using wooden pegs to prevent displacement and maintain close contact with the litter layer near the Wonka Nursery Site.

Twelve litterbags were placed in each of the three 20 × 20 m plots (replicates), resulting in 36 sample bags (three species × three replicates × four sampling times). Initial chemical analysis was conducted on the litter, after which three litterbags per species were randomly collected each month over a four-month period, following the procedure outlined by (Devendar et al., 2022). During collection, any attached material was removed, and the litter was carefully cleaned to remove roots and debris. The samples were then oven-dried at 70 °C for 24 h to reach a constant weight before undergoing further chemical analysis.

2.3.Chemical analyses

At the Debrezeit Research Center, oven-dried litter samples were crushed and passed through a 0.5 mm mesh sieve to determine total nitrogen (N), phosphorus (P), potassium (K), carbon (C), polyphenols, and lignin levels. The micro-Kjeldahl method was used to measure total nitrogen. It involved digesting 0.5 g of the material in 10 ml of concentrated H_2S_3 with a catalyst mixture of $CuSO_3$, K_2SO_3, and selenium, followed by distillation (Aguirre, 2023). Phosphorus was evaluated by wet acid digestion (Flindt et al., 2020) and measured colorimetrically at 410 nm with a spectrophotometre. The same extract was tested for potassium content using a flame photometer (Sharma & Sarmah, 2013). Provin (2014) described the dry combustion method used to calculate total carbon. The lignin and polyphenol contents were determined using the methods described by Constantinides and Fownes (1994) and Gomes et al. (2011), respectively.

2.4.Data analysis

The decomposition or nutrient release rate constant (K) for each variable was calculated using the negative exponential decay model: $Xt = X_0 * e^{-kt}$ (Wang & Xu, 2013), where Xt represents the remaining mass (g) or nutrient content (mg/g) at time t, X_0 is the initial mass or nutrient content, e is the base of the natural logarithm (e ≈ 2.718), and t is time in months. To estimate the decomposition rate constant (K per month), The exponential model was transformed to a natural logarithm, i.e., $\ln(X_t/X_o) = --kt$, The half-lives ($T_{0.5}$)—the time required for 50% of the material or nutrient to decompose—was determined using the equation: $Xt/X_0 = 0.5$ (Zhou et al., 2023), with Xt and X_0 defined as above.

All statistical analyses were performed using the JMP 11 software. To assess variations, one-way analysis of variance (ANOVA) was used, and means comparisons were performed using Tukey's Honestly Significant Difference (HSD) test, with significance set at 0.05.

3. Results

3.1. Leaf litter nutrient composition

C. macrostachyus and *H. abyssinica* had higher concentrations of N and P, but lower concentrations of C than *C. africana*. The chemical constituents of leaf litter showed significant ($p < 0.05$) differences between treatments. The leaf litter nutrient content (C, N, P, and K) of each species was evaluated, with *C. macrostachyus* having significantly higher K ($P < 0.05$) than the others (Table 1).

Table 1. Major nutrient composition of leaf litter of selected tree species (mg/g, n=12 per species)

Tree species	C	N	P	K
C. africana	434.61±0.61a*	12.21±0.14b	1.17±0.03b	6.23±0.01b
C. machrostachyus	429.15±1.51ab	15.31±0.24a	1.08±0.03a	8.45±0.03a
H. abyssinica	428.38±1.47b	15.62±0.37a	1.21±0.03a	4.06±0.11b

* Values are expressed as mean ± standard error of the means. .Means followed by the same letter in a column are not significantly different at P ≤ 0.05 as determined by Tukey Honest Significant Difference (HSD) test.

C. africana had significantly higher concentrations (P < 0.05) of C:N, lignin, polyphenol, polyphenol/N, and lignin+polyphenol:N in its leaf litter compared to H. abyssinica and C. macrostachyus. The order of lignin, polyphenol, lignin:N, C:N, polyphenol/N, and lignin+polyphenol:N contents was *C. africana* > *C. machrostachyus* > *H. abyssinica* (Table 2).

Table 2. Lignin and polyphenol composition of leaf litter of the tree species (%)

	Tree species		
Parameters	***C. africana***	***C. machrostachyus***	***H.abyssinica***
C/N	35.59±0.36a	28.05±0.54b	27.46±0.59b
Lignin (Lign)	25.51±3.35a	13.22±1.43ab	9.62±4.86b
Lignin/N	20.91±2.85a	8.67±1.08b	6.22±3.19b
Polyphenol (Poly)	5.68±0.75a	3.23±0.96b	2.11±0.01b
Polyphenol/N	4.64±0.57a	2.13±0.67b	1.36±0.04b
Poly+Lign/N	25.55±3.14a	10.80±1.74b	7.57±3.20b

* Values are expressed as mean ± standard error of the means. .Means followed by the same letter in a column are not significantly different at P ≤ 0.05 as determined by Tukey Honest Significant Difference (HSD) test.

3.2. Decomposition and nutrient release

Analysis of variance revealed highly significant differences (P < 0.001) in mass loss and nutrient release among the leaf litters of *C. africana*, *C. macrostachyus*, and

H. abyssinica, with *C. africana* differing significantly from *H. abyssinica* and *C. macrostachyus* (Figure 2). These three species exhibited distinct decomposition patterns. Leaf litter from *H. abyssinica* showed the fastest rates of mass loss and nutrient release, particularly for nitrogen, phosphorus, and potassium. *C. macrostachyus* exhibited a similar trend, closely matching *H. abyssinica*, whereas *C. africana* decomposed more slowly and released nutrients at a slower rate.

Approximately 50% of the applied biomass was lost during the first 2-3 months for H. abyssinica and 3-4 months for *C. macrostachyus*; however, *C. africana* took 7-8 months to lose the same amount of mass. Carbon (C), nitrogen (N), and phosphorus (P) half-lives were attained in 2-3 months for *H. abyssinica* and 3-4 months for *C. macrostachyus*.

In contrast, *C. africana* reached the half-life of phosphorus at 6-7 months, carbon at 8-9 months, and nitrogen at 7-8 months. Potassium (K) showed the fastest turnover, with half-lives of 1-2 months for *H. abyssinica* and *C. macrostachyus*, and 2-3 months for *C. africana* (Figure 2). These findings highlight the variation in nutrient release rates (k-values) among species, as revealed by their respective half-lives.

4. Discussion

4.1. Leaf litter nutrient content

According to Sayer (2006), analyzing the nutritional content of leaf litter is critical for understanding the soil conditions that support plant communities. As mentioned by Osman and Osman (2013), leaf litterfall is an important pathway for returning nutrients and dead organic matter from aerial plant parts to the soil surface. This study found that the nutritional composition of the various treatments differed considerably ($p < 0.05$).

C. macrostachyus had considerably greater amounts of potassium (K) ($p < 0.05$) in leaf litter compared to *C. africana* and *H. abyssinica*. Furthermore, *C. africana* showed lower quantities of N and P than *C. macrostachyus* and *H. abyssinica* (Table 1), indicating inherent species features.

The study also found that the P content was lower (Table 1) in the abscised leaves of all three tree species than that of N and K. This discovery is consistent with recent studies (Getachew et al., 2015, 2016; Meier & Leuschner, 2014), which found that trees absorb (re-translocate) more than half of the P from deciduous leaves before they fall. Phosphorus is one of the most closely cycled main nutrients in plants, with perennials often reabsorbing 40-65% of N and P from their leaves prior to abscission (Estiarte et al., 2023). This mechanism recycles nutrients internally and uses them to create new tissues (Brant & Chen, 2015; Gonzales & Yanai, 2019).

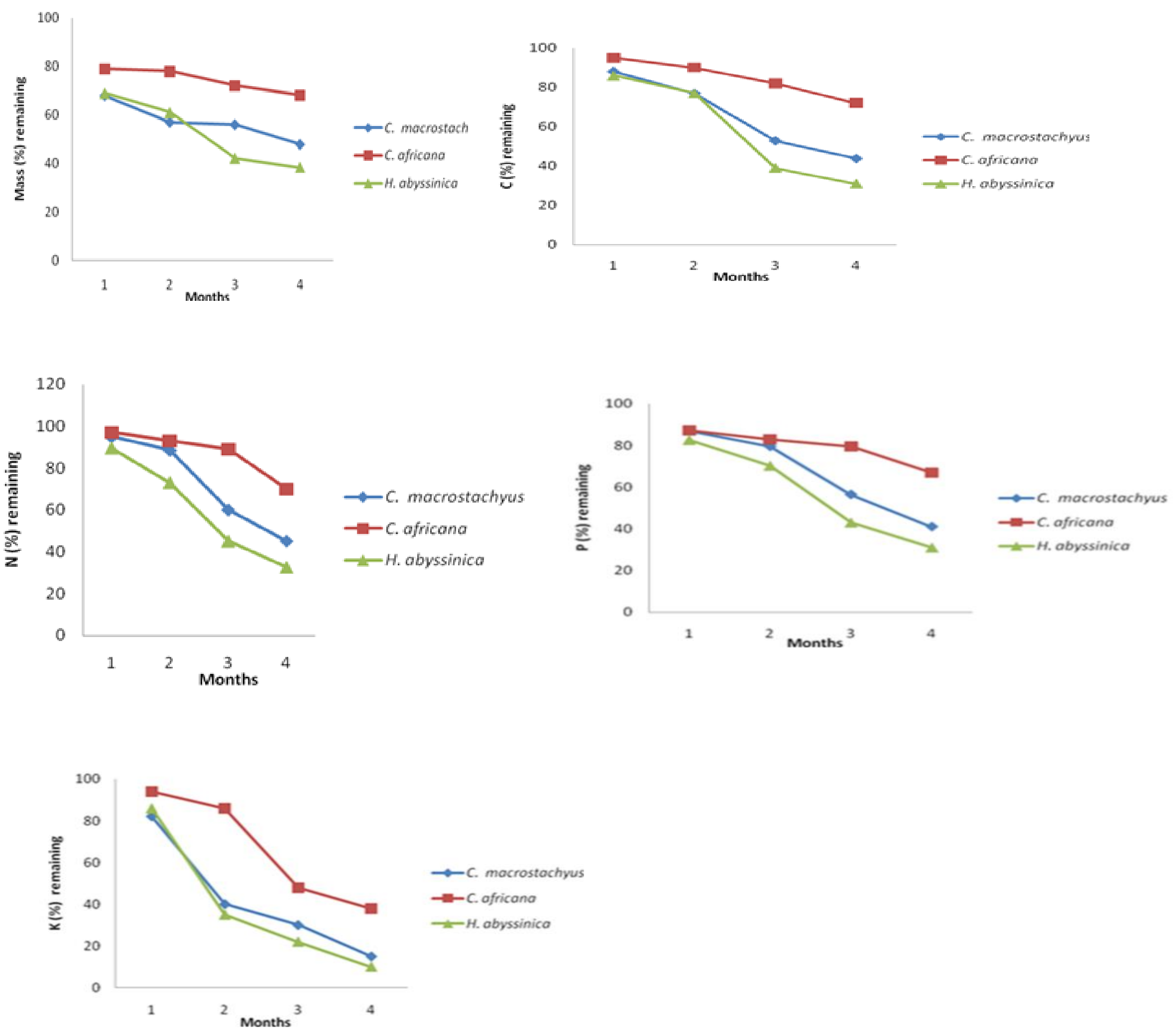

Figure 1. Mass and nutrients remaining during 4 months of decomposition of leaf litter of *C. africana*, *C. macrostachyus* and *H. abyssinca*

4.2. Decomposition and nutrient release

During the 4-month decomposition period, the mass loss and nutrient release rates for *C. macrostachyus* and *H. abyssinica* exceeded 50%, whereas those for *C. africana* were less than 50%, with the exception of potassium. This means that *C. macrostachyus* and *H. abyssinica* degrade and release nutrients more quickly than *C. africana*. This finding is consistent with a study by Biru et al. (2022), who found that mass loss and nutrient release for *C. macrostachyus* exceeded 50% during a 12-week decomposition experiment. Furthermore, Teklay (2007) observed only 43% mass loss for *C. africana* after 16 weeks.

Climate and litter quality parameters influence litter decomposition rates (such as leaf hardness, N, P, lignin content, and polyphenols) (Xu et al., 2010). This study focused primarily on litter quality because it has a greater impact on decomposition than climate conditions (Prieto et al., 2019).

Limiting elements such as nitrogen (N) and phosphorus (P) also have an impact on decomposition and nutrient release rates. According to Berg et al. (2020), the availability of these elements determines the initial decomposition stage, whereas carbon loss in later stages is caused by the degradation of recalcitrant components, such as polyphenols and lignin. According to Abay (2018), nitrogen is a useful predictor of early decomposition rates, whereas lignin and polyphenols are important in the later stages. The early decomposition variables differ from those influencing slow-decomposing litter, which affects soil organic matter and carbon sequestration, with similar variables having opposing effects at different stages (Gill et al., 2022).

In this study, the nitrogen contents and chemical composition of leaves were investigated from *H. abyssinica*, *C. macrostachyus*, and *C. africana*. The results revealed that *H. abyssinica* and *C. macrostachyus* had much higher nitrogen concentrations than *C. africana*, which had higher levels of lignin, polyphenols, and lignin/N ratios. *C. africana's* sluggish decomposition could be attributed to its lower nitrogen concentration and greater C:N ratio of lignin, polyphenol, lignin/N, polyphenol/N, and lignin+polyphenol/N when compared to *H. abyssinica* and *C. macrostachyus*. These findings support Sánchez et al. (2018), who observed that higher initial concentrations of polyphenols and lignin, as well as their nitrogen ratios (polyphenol/N, lignin/N, lignin + polyphenol/N, and C/N), result in slower breakdown and nutrient release.

Kumar and Goh (2003) notes that plant materials with N content below 1.7%, lignin content above 15%, polyphenol content exceeding 3%, and a C/N ratio greater than 20 typically immobilize nitrogen. However, this does not apply to all species. In this study, *C. africana*, *C. macrostachyus*, and *H. abyssinica* did not fit this generalization, as their N content and C/N ratios exceeded these limits. Additionally, *C. macrostachyus* did not immobilise N despite having over 3% polyphenol content.

The litter quality attributes of *C. macrostachyus*, including C, N, polyphenol, and lignin concentrations and ratios, are similar to those observed by Gindaba et al. (2004), but the P, C/N, and lignin/N ratios were higher in this study as compared to Gindaba et al. (2004) and; Mahari (2014). *C. africana's* C, N, and P values were similar to those of Mahari (2014), but the C/N, lignin, and lignin/N ratios were higher in this study.

A lignin content exceeding 15% can hinder or delay nitrogen release (Rahman & Motiur, 2012), as 15% lignin is critical for decomposition, obstructing cellulose degradation (Khan & Ahring, 2019). This aligns with the current study, which found reduced nitrogen release and decomposition for *C. africana*, which had a lignin content above 15% (Table 2).

The slower nitrogen release from *C. africana* compared to *H. abyssinica* and *C. macrostachyus* may be due to tannin-protein interactions causing microorganism toxicity and resistance to substrate degradation (Olumuyiwa et al., 2020). Additionally, polyphenols may form non-degradable complexes with cell wall carbohydrates, thereby contributing to protein precipitation (Silanikove et al., 2001).

This study supports Li et al. (2011)findings that low-quality litter, characterized by lower N concentration and higher C/N ratio, decomposes more slowly than high-quality litter, implying that the N content of leaf litter in the initial decomposition stage is a reliable predictor of the decomposition rate. According to Giweta (2020), nitrogen from litter decomposition helps meet the needs of decomposers and stimulates decomposition.

A study by Zhao et al. (2022) highlighted that decomposition rates are influenced by both nutrient content and morphological characteristics. For example, leaf surface structure and physical toughness can affect decomposition rates, as noted by (Pérez-Harguindeguy et al., 2000). This study observed that *C. africana* decomposed more slowly because of its thick and tough leaves with major veins and midribs, likely due to higher lignin concentration. Conversely, *C. macrostachyus* and *H. abyssinica* decomposed faster, attributed to their thinner, softer leaves and lower lignin concentration. Akinyele and Donald-Amaeshi (2021)reported similar findings, noting that *C. macrostachyus* decomposes more quickly owing to its lower lignin content and softer leaves.

In general, *C. macrostachyus* and *H. abyssinica*, while decomposing rapidly, may not significantly contribute to short-term soil organic carbon, but can supply nutrients to crops. *C. africana*, with slower decomposition and lower nitrogen release within 4 months, may be less effective for annual cropping systems but could be more important for perennial systems where nutrients are required over longer periods.

5. Conclusion

The study found substantial differences in nutrient composition and decomposition rates across the tree species namely *C. africana*, *H. abyssinica*, and *C. macrostachyus*. *H. abyssinica* and *C. macrostachyus* exhibited faster mass loss and nutrient release, but *C. africana* had lower nitrogen content and higher quantities of lignin and polyphenols, resulting in slower decomposition and delayed nutrient release.

It is recommended that all three species be incorporated into agroforestry operations, as their combined contributions provide both immediate and long-term advantages. *H. abyssinica* and *C. macrostachyus* improve soil fertility by decomposing quickly, whereas *C. africana* ensures soil surface stability over time. Furthermore, fast and slow decomposing species provide significant goods and ecosystem services that contribute to long-term agricultural output.

Future studies should evaluate seasonal differences in litter quality, extend decomposition monitoring beyond four months, and examine the impacts of microbial activity and litter mixing. Long-term influences on soil parameters as well as the relationship between decomposition rates and crop performance should also be investigated. These findings will help guide the effective usage of these species in agroforestry systems.

Acknowledgements

The Authors are grateful to Debre Markos University for financial support to this research work and also Debre Zeit Agriculture Research Center for allowing us to do soil and plant nutrient analysis in its Laboratory

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